Liquid Argon Circulation, Temperature Profile, and Impurity Distribution in the 10kT LBNE Cryostat

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ABSTRACT

Document shows results of a Computational Fluid Dynamics (CFD) model of the 10kT cryostat. The cryostat liquid circulation was modeled using ANSYS CFX commercial CFD code. Results are shown for temperature and impurity distribution, velocity profile, pressure/force distribution on the CPA planes from the buoyancy driven fluid, as well as Liquid surface velocity and evaporation contour. The preliminary model is a 2D symmetric cross section of the cryostat, which may be further analyzed as 3D if computational resources are sufficient.

Model and Argon Specifics:

Model Physics:

Turbulence Model:	k-ε
Buoyancy Model:	Boussinesq approximation
Turbulence Numerics:	High Resolution
Advection Scheme:	High Resolution
Convergence Criteria:	1e-6 RMS Residual
Two Meshes:	Uniform Hexahedral @ 2cm & 1cm

Fluid Specifics:

Fluid:	Liquid argon @ 14.5 psia
Molar Mass:	39.948 kg/kmol
Saturation Temperature:	87.175K
Density:	1396.2 kg/m^3
Viscosity:	261.30 μPa*s
Specific Heat:	1117.1 J/kg*K
Volume Expansivity:	0.0044369/K
Impurity Flux:	Unity entering through liquid surface
Impurity Diffusivity:	0.00082483 cm^2/sec

Model Dimensions:

Cryostat Dimensions:	See Figure 1

Boundary Conditions: (See Figure 1)

Liquid Surface:	Free slip wall @ 87.175K with Impurity Flux
APA Planes:	open interface
CPA Planes:	Impermeable wall w/ heat transfer
Field cage:	Superficial porous subdomain; Through plate: 4cm thick; k_{loss}=4570 m^{-1} Transverse to plate; k_{loss}=457 m^{-1}
Outer wall heat:	6 W/m^2
Electronics:	15 W/m = 21.429 W/m^2

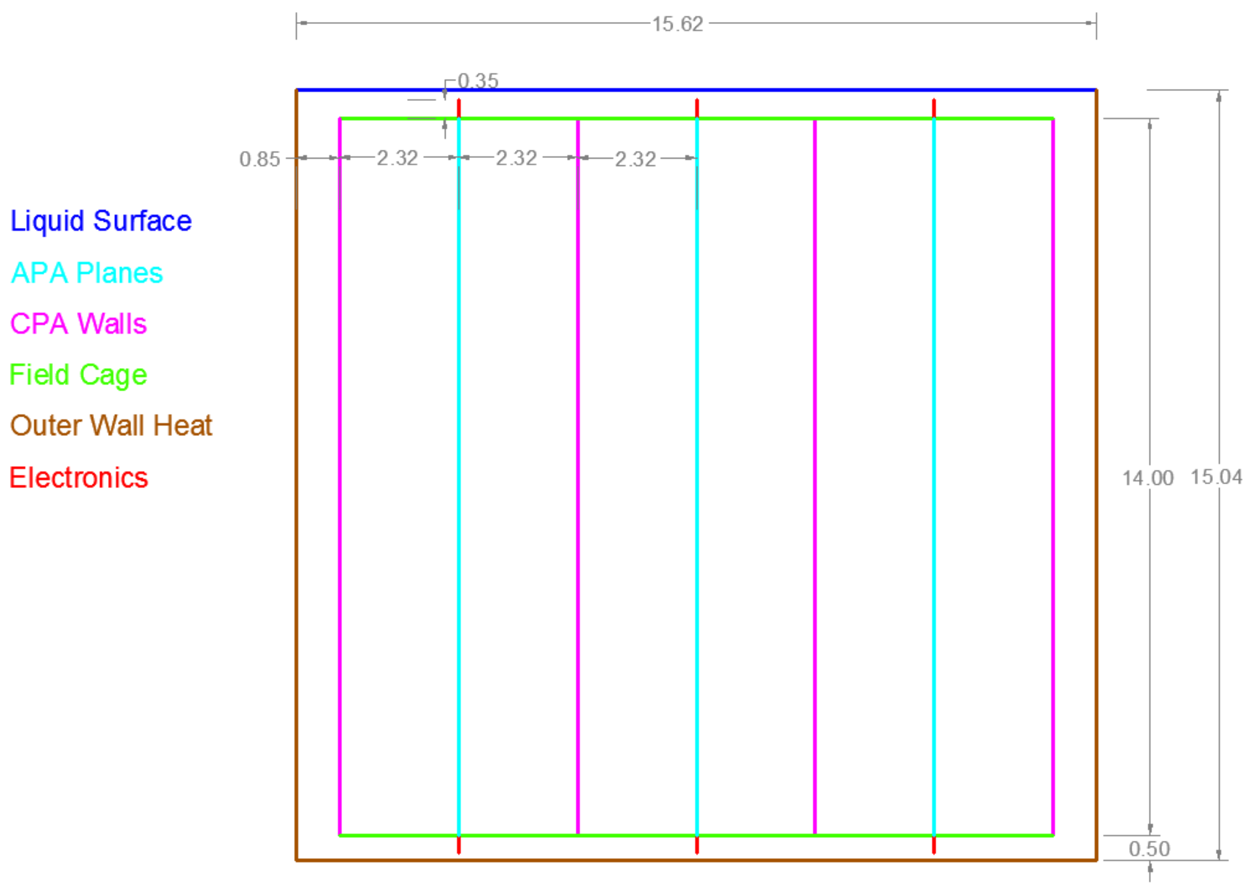

Figure 1: Model dimensions and boundary condition locations

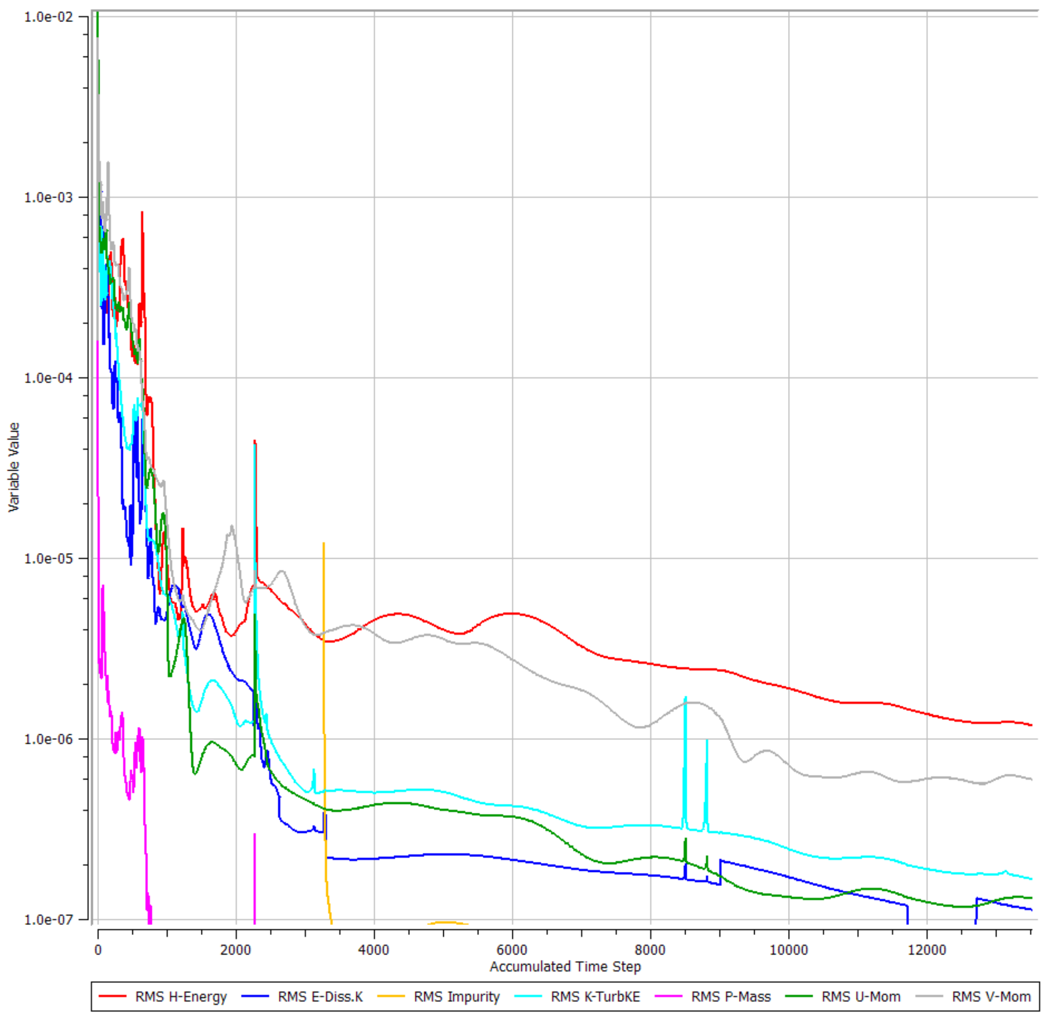

Figure 2: RMS solver residuals showing excellent numerical convergence

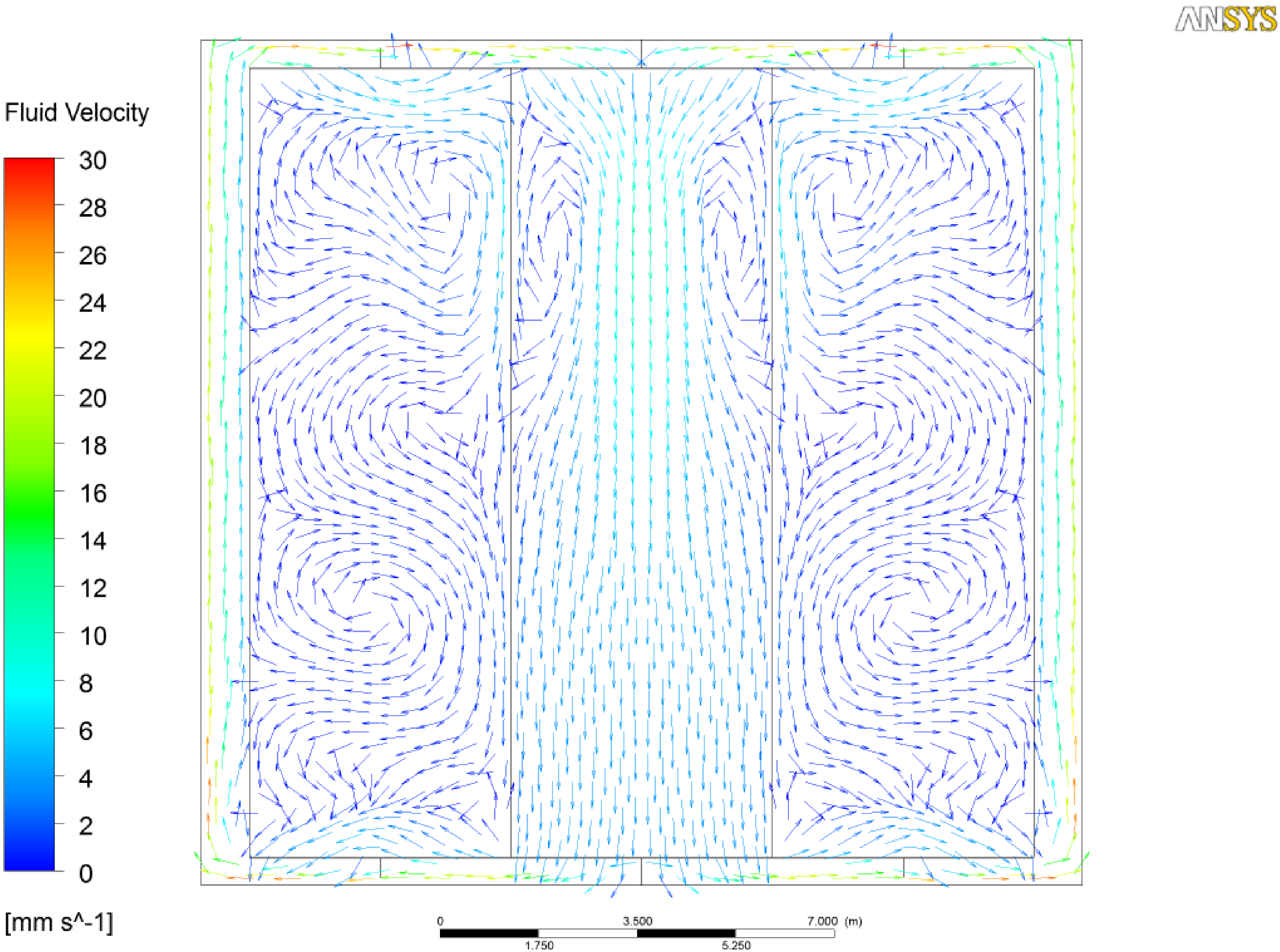

Figure 3: LAr Velocity Profile

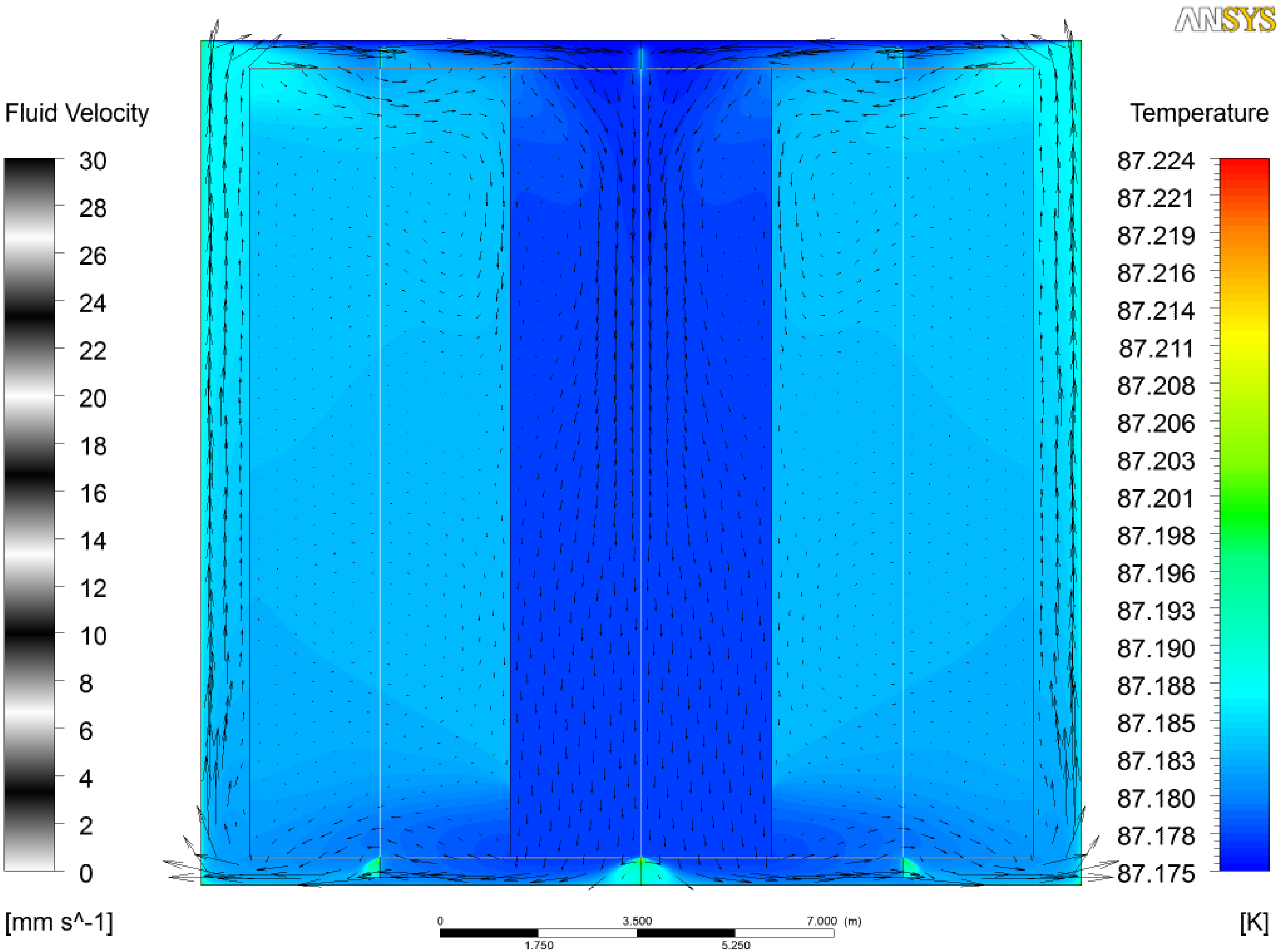

Figure 4: LAr temperature profile with velocity magnitude shown by arrow size.

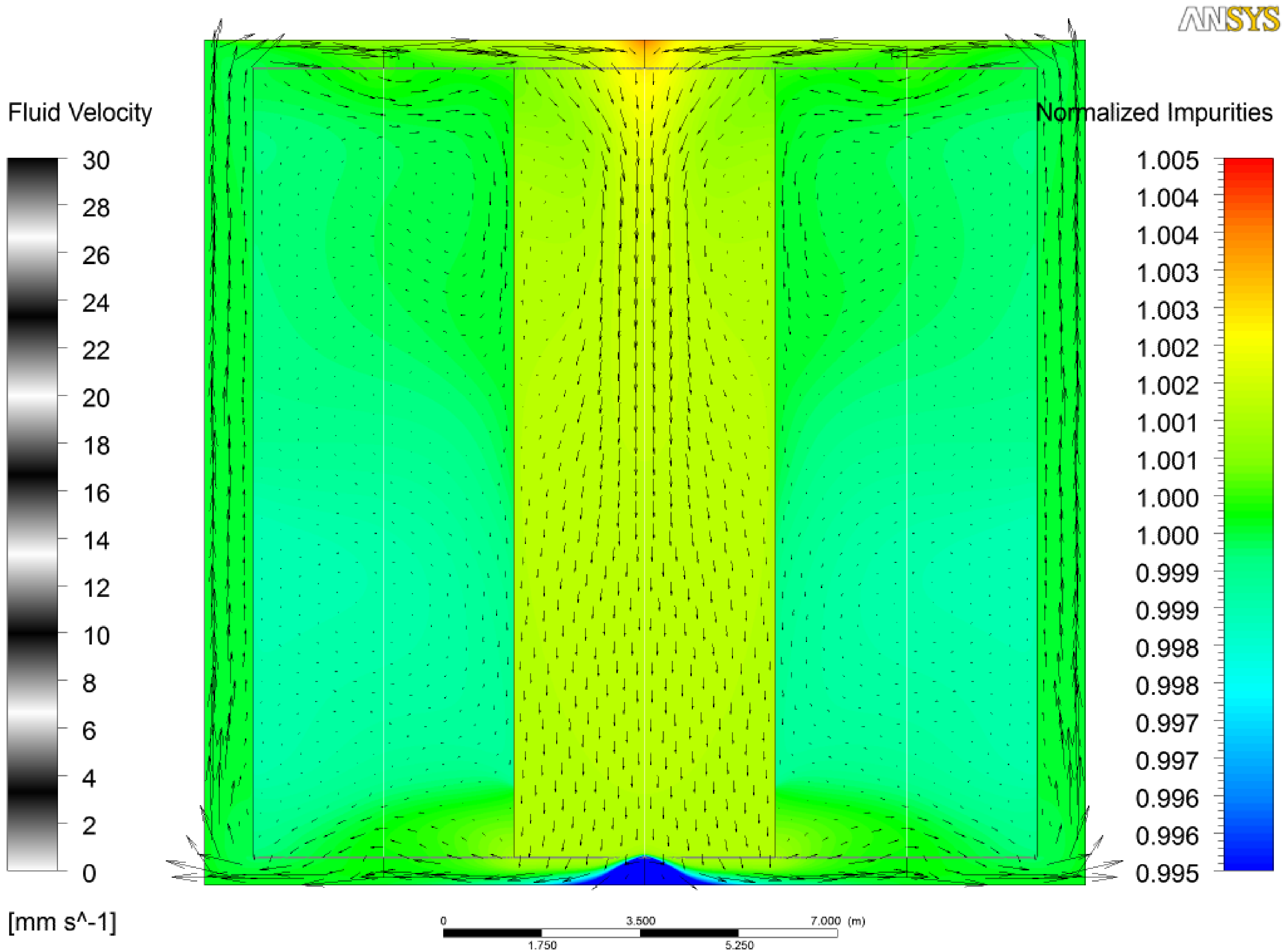

Figure 5: Normalized impurity profile showing nearly homogeneous field; (1 = average impurity level)

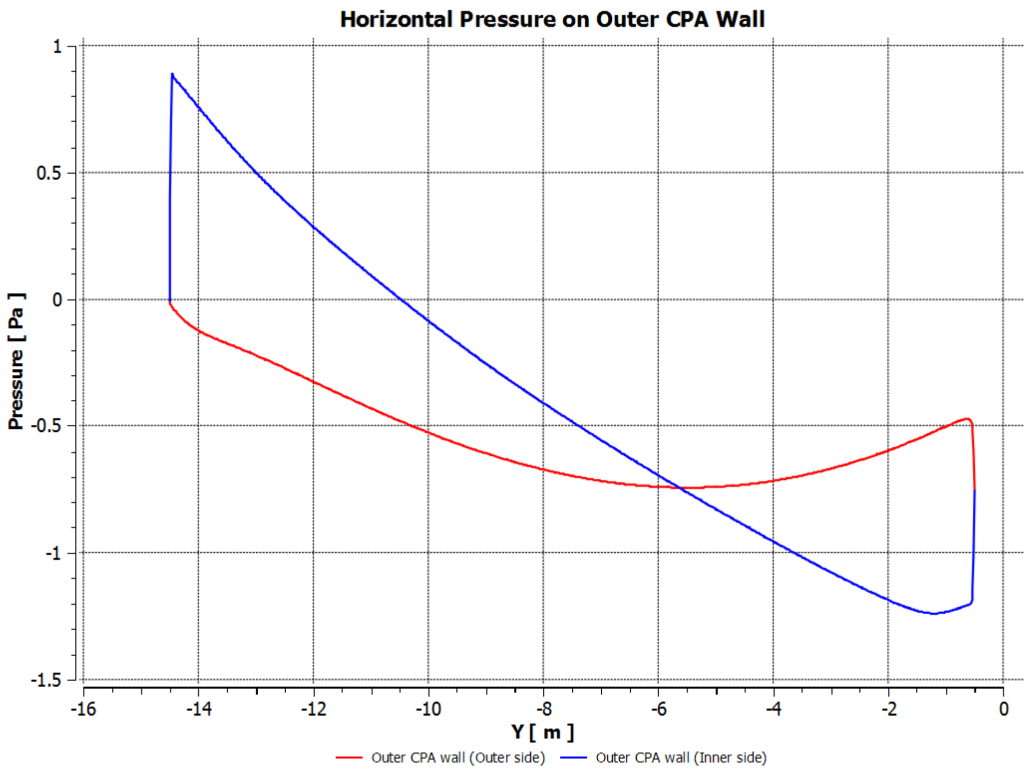

Figure 6: Normal Pressure on Outer CPA Walls Due to fluid motion (very low)

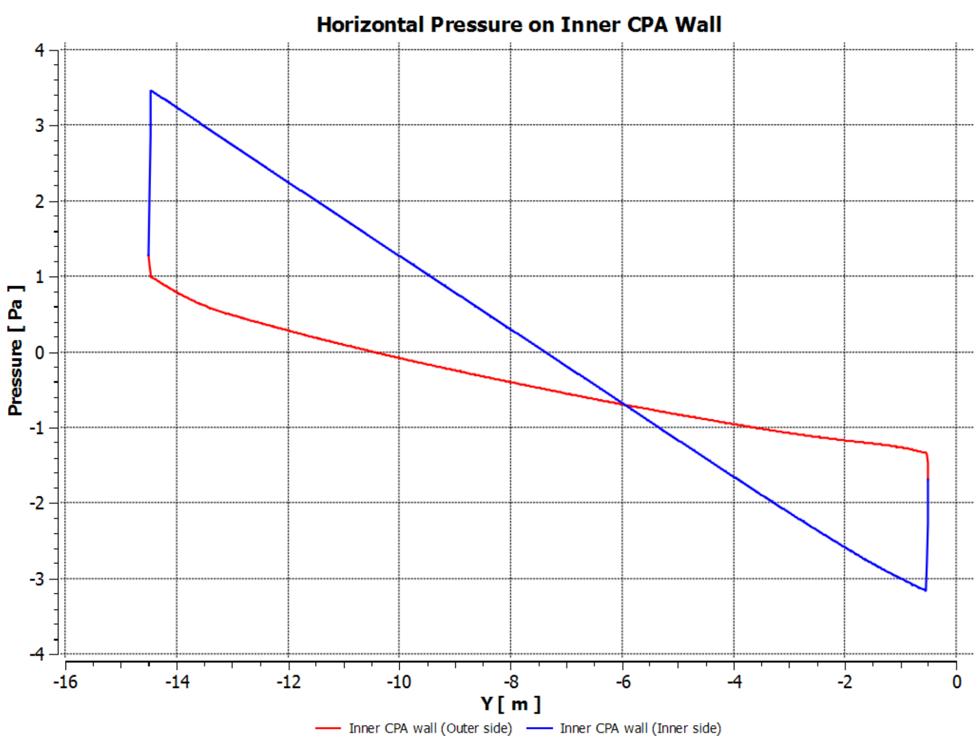

Figure 7: Normal Pressure on Inner CPA Walls due to fluid motion (very low)

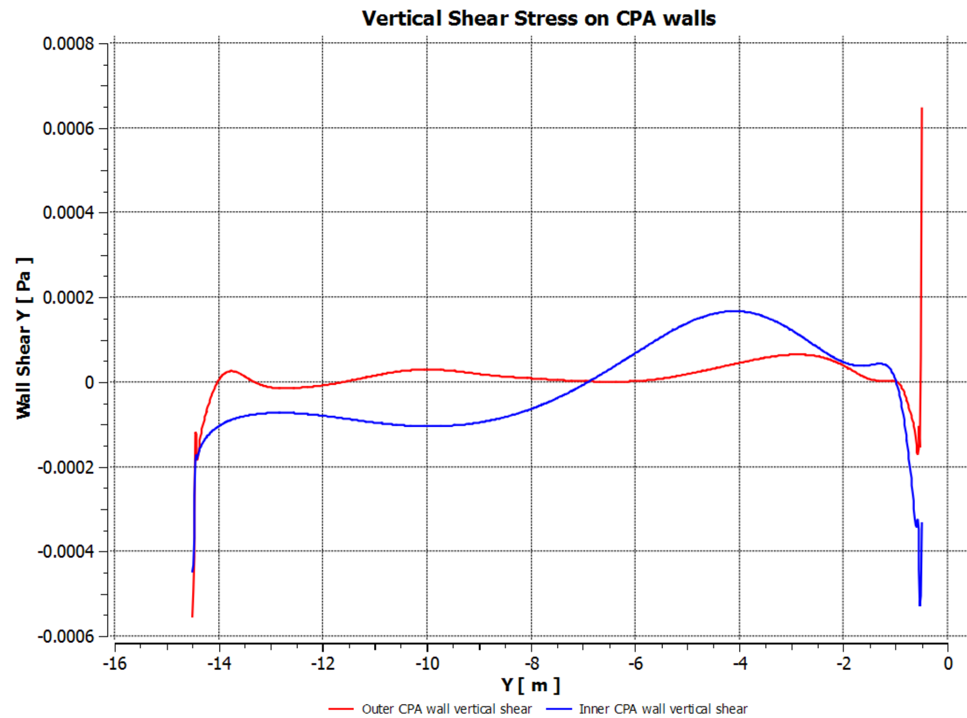

Figure 8: Vertical fluid shear pressure on CPA walls due to fluid motion (very low)

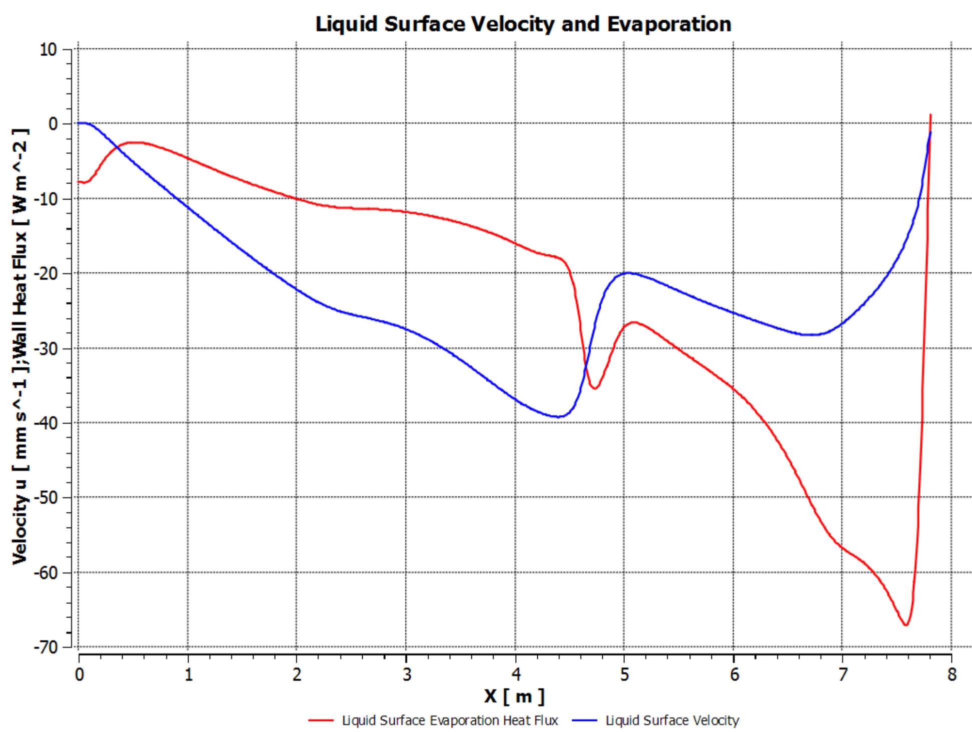

Figure 9: Liquid surface heat flux and Velocity from center (0m) out to cryostat wall (7.81 m)

Positive Ion Generation and Resulting Concentration Field:

Positive Ions generate inside the field cage, and travel through the liquid argon by the superposition of the convective fluid motion and their drift velocity. They are neutralized when they reach the CPA plane or pass through the field cage. Mass/charge transport takes place by advection as well as molecular and turbulent diffusion. The volumetric generation and neutralization was modeled and results for ion velocity and concentration shown in Figures 10 and 11.

Ion Boundary Conditions:

Ion Generation rate:	1100 ions/(cm^3 *s)
Drift velocity:	8 mm/sec from APA to CPA
Molecular diffusion:	0.00082483 (equal to thermal diffusivity)
Absorbtion:	quickly absorbed to zero by CPA planes and field gage

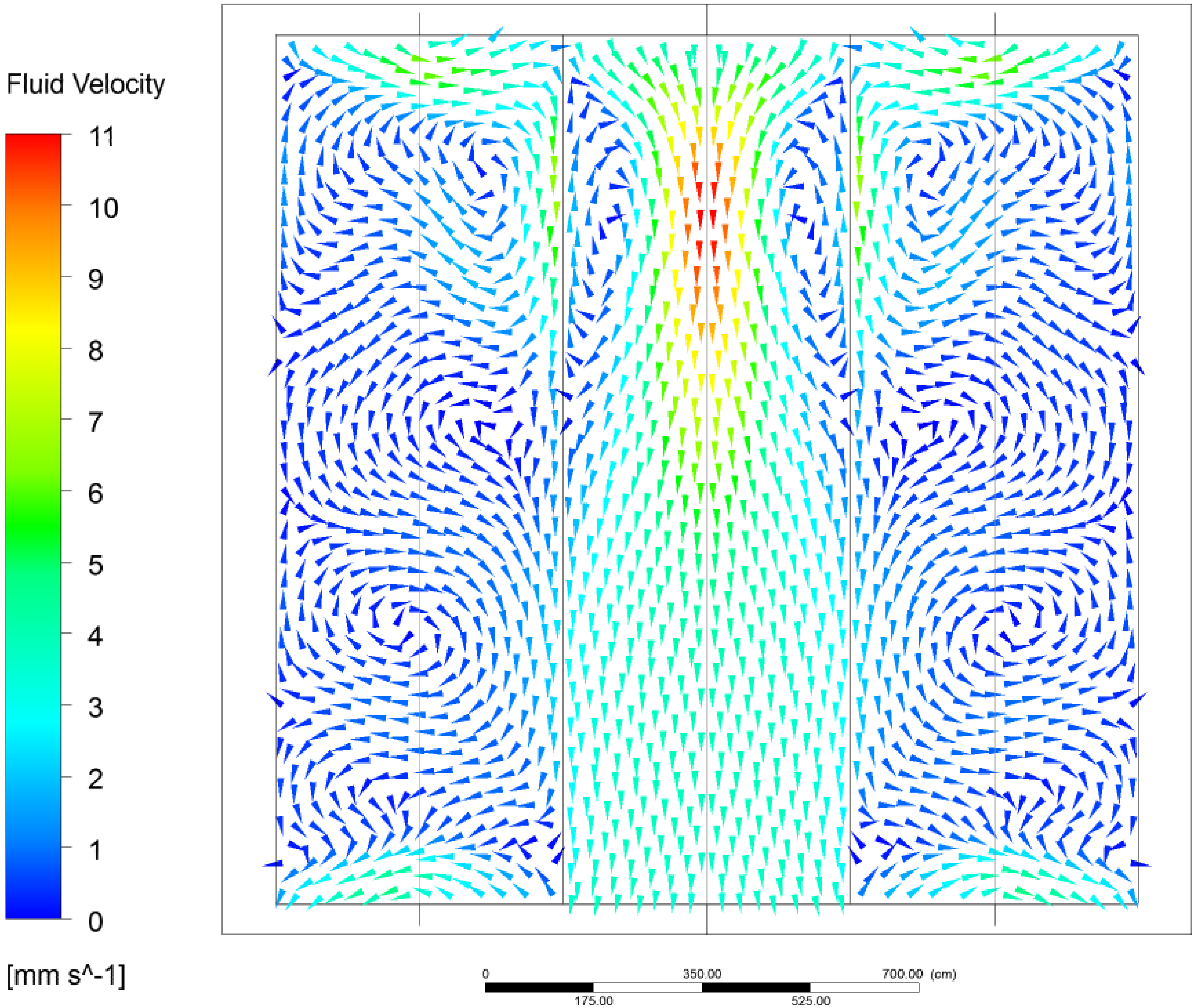

Figure 10: Liquid Argon velocity in Field cage.

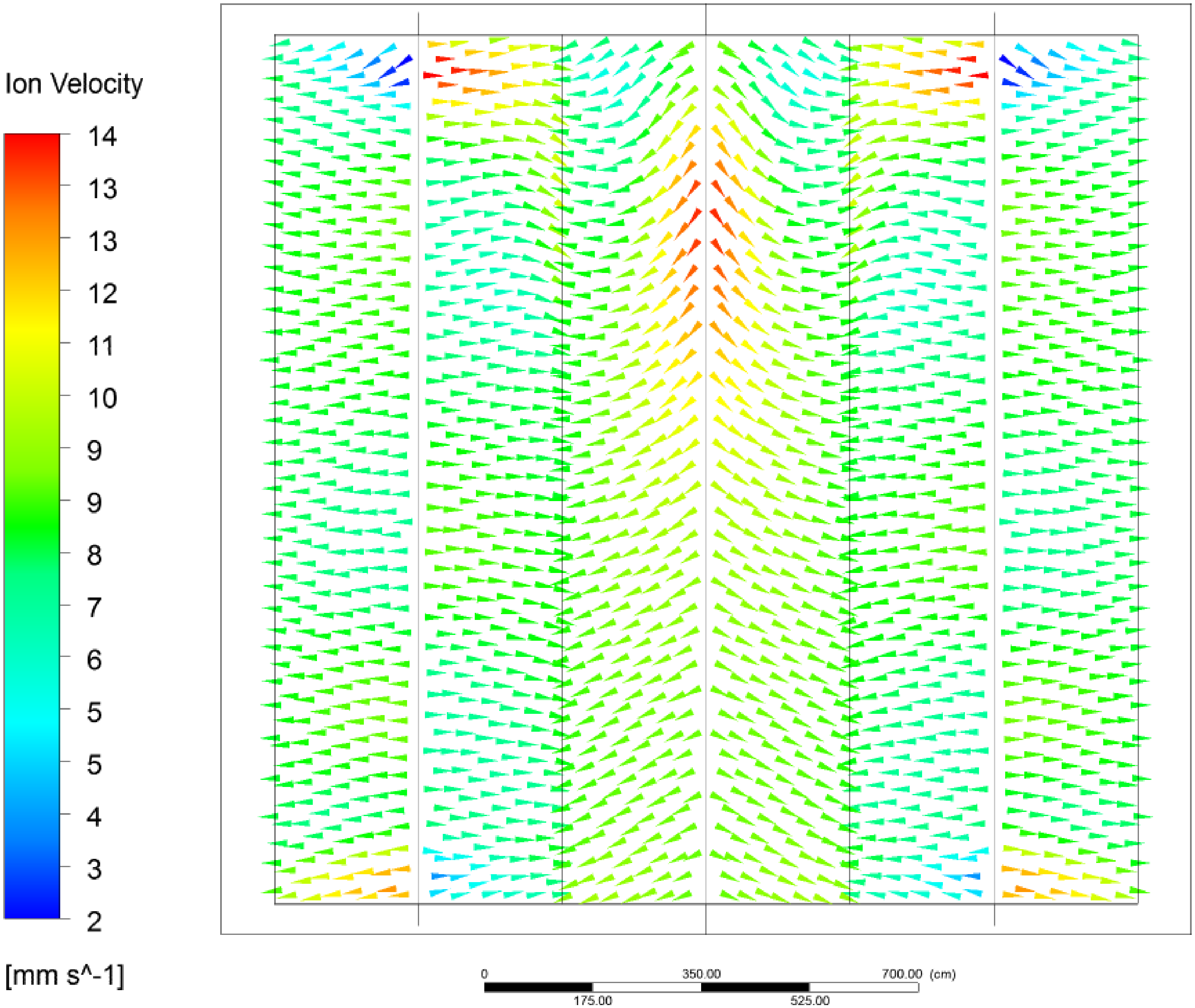

Figure 11: Net Ion velocity = Fluid velocity + Drift velocity of 8 mm/sec from APA to CPA

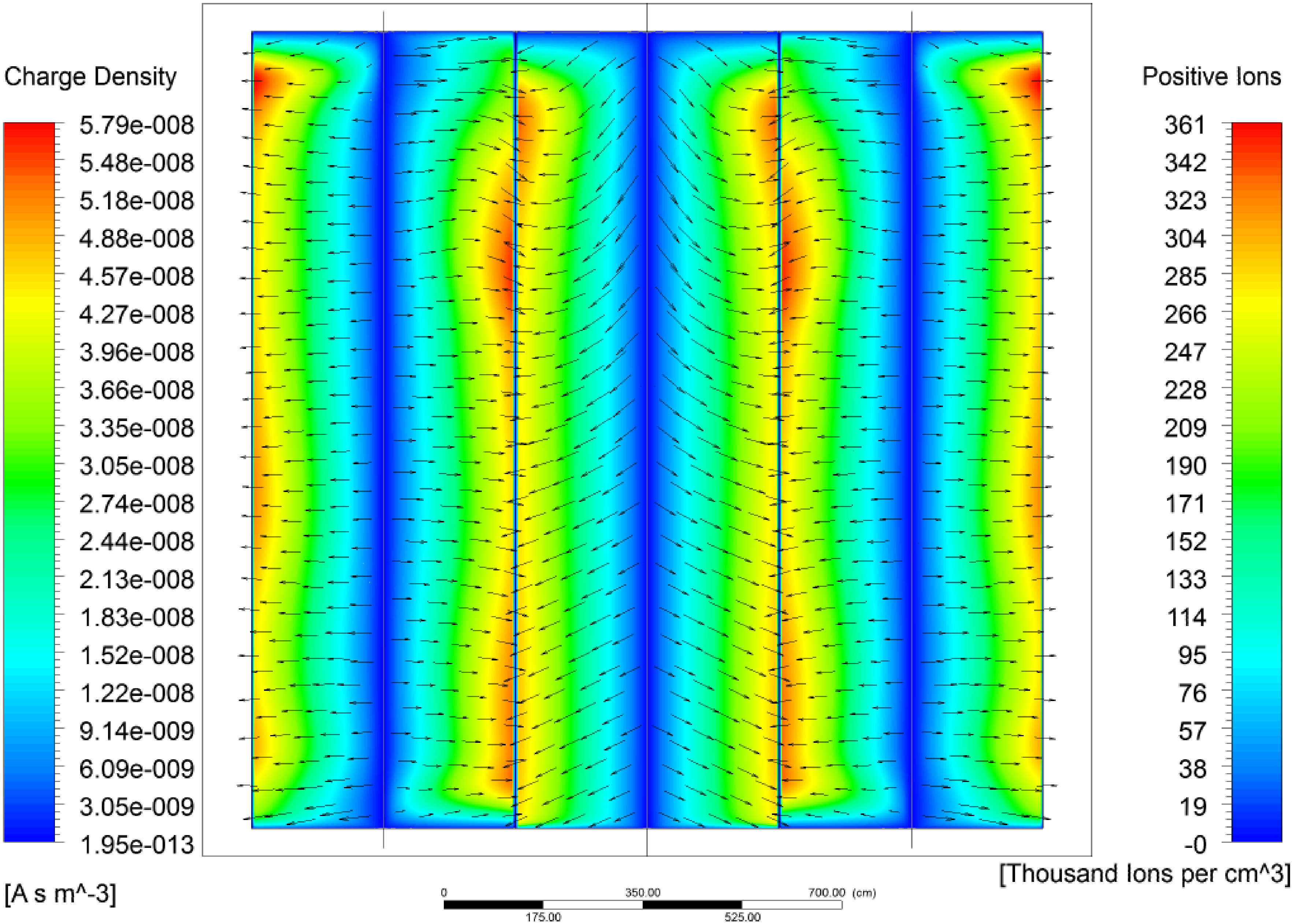

*Figure 12: Charge Density and Ion Density inside Field cage with generation of 1100 Ions / (cm^3 * s)*